Cost and Process Information Modeling for Dry Machining

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Abstract

The cost of using coolant in machining industry world-wide is very high. Through a literature survey, it costs multi-billion Dollars for coolant acquisition and disposition in industrialized countries. Furthermore, chemical substances contained in coolant are very harmful to environment and machine shop workers. Dry machining is inevitably the future trend in machining industry. In order to help dry machining methods be smoothly adapted by the industry, this paper provides an information model for cost and process of dry machining. New software tools and knowledge databases can be developed based on this model to help users to choose optimal process parameters, resources, and estimate machining time and cost. This model is in its early stage. Extension to this model is expected as dry machining technology advances.

1 Introduction

Used coolant from machining processes is harmful to both environment and human health. Chemical substances that provide the lubrication function in the machining process are toxic to the environment if the cutting fluid is released to soil and water. The chemical substances in coolant caused serious health problems to workers who are exposed to the coolant in both liquid and mist form.

Cost of using coolant is increasing as the number and the extensiveness of environmental protection laws and regulations increase. According to documented data and a survey, cost of using coolant is about 48 billion Dollar a year in U.S. [1], about one billion German Mark in Germany [2], and about 71 billion Japanese Yen in Japan based on our survey and calculations.

The way to eliminate coolant pollution is to use coolantless cutting, namely dry machining, technologies. However, tools for dry machining are still being developed. New tools and tool coating (ceramic, diamond, multi-layered) methods have been developed to reduce the cutting heat generation and to extend the tool life. Cool air cutting is under development. A mix of cool air and environmentally friendly oil, like vegetable oil, is being researched. Results shows that dry grinding and machining are as good as wet machining in some cases. [3].

In order to help applying dry machining technologies, information models for dry machining processes are developed, which will enable new software tools and databases development. New software tools will help engineers plan the process by selecting optimal process parameter, define cutting operations/steps, and link with CAD systems. Information model can be directly translated into database schema for developing databases as process data repository.

It is important to reduce the presence of harmful substances in manufacturing. Research on working towards emission free manufacturing has been conducted in the Mechanical Engineering Laboratory in Japan [4]. The work includes high-speed dry machining and grinding.

The scope of the work described in this paper is within the machining cost analysis to justify dry machining research and information modeling. Section 2 of this paper provides a cost analysis of wet machining and possible saving provided by dry machining. Section 3 reviews the current state of dry machining technologies. Section 4 provides an initial information model for dry machining. Section 5 provides concluding remarks and points out future research directions.

2 **Environmental and Financial Effects of Wet Machining**

Nowadays, coolant has to be used in machining some metals which are hard. Examples are high speed steel and titanium alloys. Without coolant, they are extremely difficult to be machined. Costs of coolant usage and disposal are significant and keep increasing as environmental the number and extensiveness of protection laws and regulations increase. The coolant used by wet machining causes serious health problems to machine shop workers. Especially, the extreme pressure agent in coolant usually contains chlorinated paraffin, which is transformed into dioxin by the heat and high temperature generated by the cutting process. Furthermore, many workers in industrialized countries are being exposed to harmful coolant.

Estimated 100 million gallons of metalworking oil are used per year in U.S. Coolant consumption is estimated higher than 100 million gallons per year in U.S. [5]. The cost of purchasing and disposing cutting fluid is about 48 billion dollars a year[1]. In Germany, coolant consumption is about 75,500 tons a year [6]. The cost of purchasing and disposing coolant is about one billion German Mark [2]. In Japan, cost of purchasing coolant is about 29 billion Japanese Yen a year, according to a survey of coolant purchasing cost in Japan, published by Japan Lubricant Economy in 1984. The figure is about the same nowadays. Coolant consumption is as follows: 100,000 kiloLiter water-immiscible (disposal cost 35-50 Yen per liter), 50,000 kiloLiter water-soluble coolant without chlorine (disposal cost 300 Yen per liter), and 10,000 kiloLiter water-soluble coolant with chlorine (disposal cost 2250 Yen per liter). The figures were provided by Japan Metalworking Oil and Coolant Association and NissekiMitsubish. From the above figures, the estimated coolant disposal cost alone in Japan is about 42 billion Yen. The total coolant purchasing and disposal cost is about 71 billion Yen a year.

Long-term contacting with coolant due to occupation can cause serious health problems. Skin exposure is the primary route of exposure. Cutting fluids are primary causes of occupational contact dermatitis, which may involve either irritant or allergic mechanisms. Non-water-miscible fluids usually cause skin disorders such as foliculitis, oil acne, keratoses and carcinomas. The mist droplets can cause throat, pancreas, rectum, and prostate cancers, as well as breathing problems and respiratory illnesses. One acute effect observed is mild and reversible narrowing of airways during exposure to cutting fluid mist. About 1 million workers are exposed to coolant in U.S. [5]. About 220 thousand metal cutting machine operators could be exposed to coolant in Japan, according to the 1995 Census of Japan.

Due to both financial burden and health problems created by wet machining, dry machining is inevitably the future trend for metal cutting industries.

3 **A Review of Dry Machining Technologies**

Both ordinary tools and coated tools are used in dry machining research and development activities. Ordinary high speed steel tools, aluminum ceramic tools, Cubic Boron Nitride (CBN), and ceramic can be used in machining various kinds of materials without coolant presence. Coating tools usually have longer tool life than non coated tools if coating is done properly to be effective. Coating provides insulation and lubrication in cutting. Materials used for coating cutting tools include TiAlN (Titanium Aluminum Nitride), TiN [7], and diamond. Diamond coated tools generally outperform other coated tools [8]. Recently, multi-layered coating tools have also been demonstrated to provide multiple functions[9]. One layer is several nanometer thick. Each layer provides a specific function, e.g., heat insulation, anti wear, or lubrication. These three functions are the major functions provided by coated materials.

In addition to new cutting tool technology, cryogenic machining technology has also been investigated. Cooling-air dry grinding has been demonstrated in CBN dry grinding using CBN grinding wheel. Based on Yokogawa's experiment, the grinding results were as good as using coolant [3]. Cryogenic machining is also feasible and used in several prototype high speed dry machine tools in the Advanced Engineering Center in the Physical and Chemical Research Institute in Japan. However, potential problems exist in cryogenic machining systems, for example, extra noise generated by the cold air supplying system and frost developed outside cold air pipes. These problems have to be resolved before cryogenic machining processes can be applied in industry.

Dry machining processes have been applied to cut several types of materials, from soft to hard, with different tools [6]. CBN and ceramic tools can cut cast iron dry, coated tools (TiN coated) should be used for dry cutting steel to avoid flutes jammed by chips, especially in the case of drilling. In general, it is difficult to cut super alloys and titanium without coolant. High speed, low cutting depth, cryogenic machining is the trend for cutting hard metals.

Because of the complexity nature of dry machining, it is necessary to develop new software tools to help manufacturing engineers plan the dry machining process based on product design. Information modeling of the process is the first step towards software and databases development.

4 **Information models for machining**

The developed information model has two parts. The first part is an activity model, which has been develop to represent the machining process planning activities, wet or dry machining processes. It is decomposed into four subactivities, as shown in Figure 1.

The first subactivity, A1, is to determine the machining process based on product design, under the control of tolerance and surface roughness standards, and supported by machining knowledge base. It includes specifying detailed operations and choosing process parameters, such as cutting speeds, feed rates, and depths of cut.

The second subactivity, A2, is to select machining resource. This includes selecting machine tools, cutting tools, fixtures, stock materials, etc. A2 can be further decomposed into three subactivities, as shown in Figure 2. It includes the following three subactivities: A21 is to select appropriate machine tools, A22 is to select cutting tools and fixtures that are used on the selected machine tools, and A23 is to select labor skills to operate the machine tools. These subactivities are all controlled by engineering requirements of the product and supported by a machining resource model.

The third subactivity, A3, is to estimated environmental impact. Specifically in wet machining, handling of coolant, chips handling, power consumption should be carefully analyzed. A3 can be further decomposed into four subactivities, as shown in Figure 3. A31 is to estimate energy consumption of the whole machining process, based on some energy consumption models. A32, A33, and A34 are to estimate gas, liquid, and solid wastes emission, respectively. It is important to estimate, track, and record emissions for machining processes for future references.

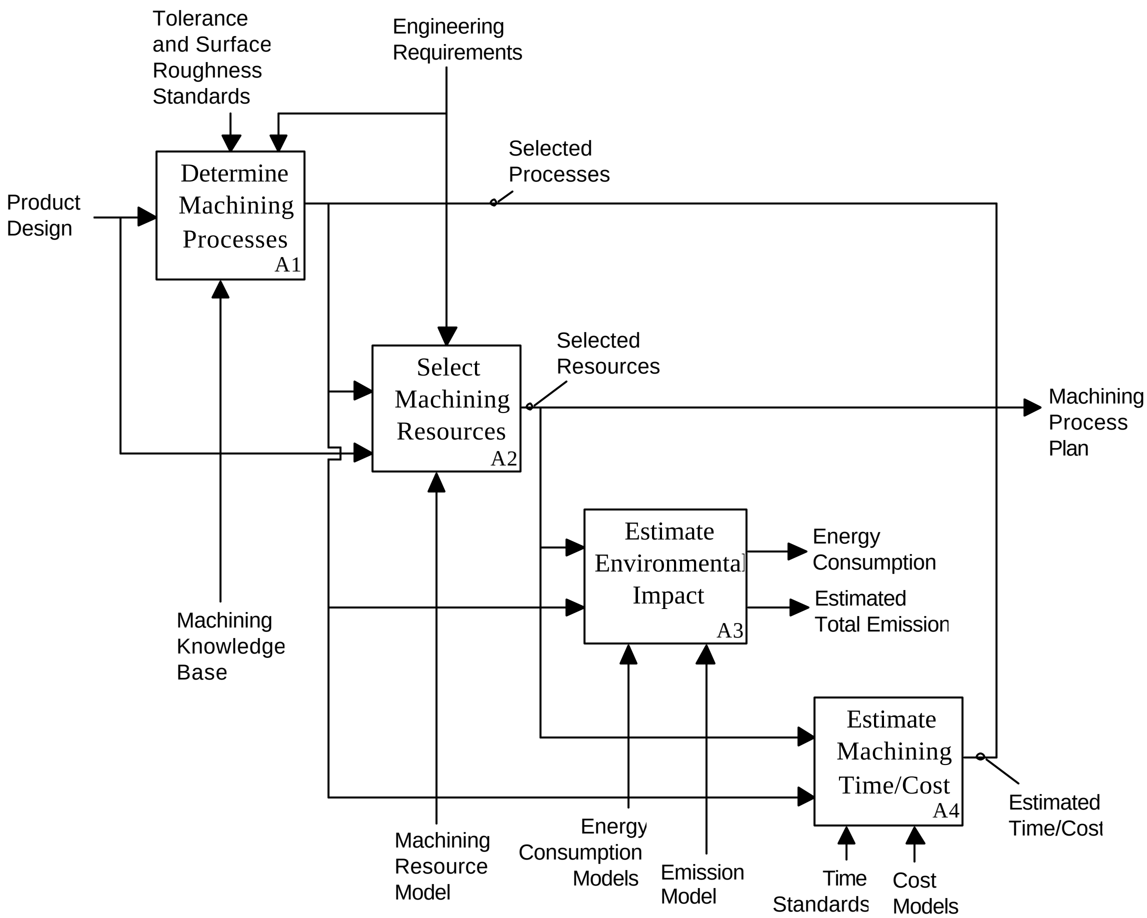

Figure 1 Machining Process Planning Activity

The fourth subactivity, A4, is to estimate machining time and cost to ensure that products can be made within specified manufacturing cost and time limits. A4 can be further decomposed into five subactivities, as shown in Figure 4. They are the time and cost estimation in details. A41 is to estimate the time and cost of workpiece transferring from one workstation to another, based on selected resources, selected processes, time standards, and cost model. A42 is to estimate the time and cost of loading and unloading workpieces at a workstation. A43 is to estimate the time and cost of setting up workpieces at a workstation. A44 is to estimate the time and cost of machining workpieces. A45 is to estimate the overhead cost of machining workpieces.

The activity model sets a context in which data and message are exchanged among different software components and between software and data repositories. Based on the developed activity model, an object model was developed.

The object model is used to represent information involved in machining processes. Based on the object model, new process planning software, software interface specifications, and databases can be developed. Classes and their relationships are the main parts of this object model. Uniform Modeling Language (UML) [11] is used for object modeling. A related process planning model has also been developed [12], but this model dose not take into account of environmentally conscious machining. Machining processes and detailed processes, emission, machining parameters, resources are shown in Figure 5.

A detailed view of machining resource object model is modeled in Figure 6. It has definitions of possible resources used in machining process, e.g., machine tool, cutting tool, machine capability parameters, tool capability parameters, labor skills, and fixturing devices information.

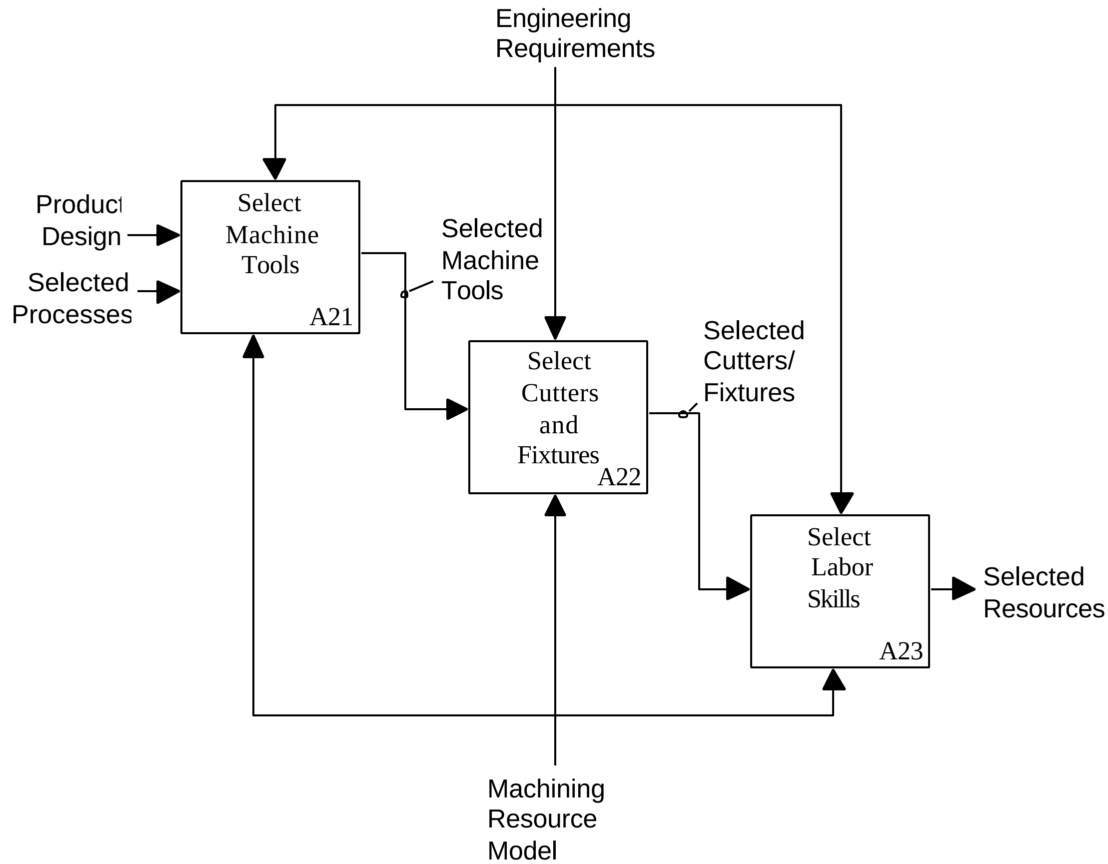

Figure 2 Select Machining Resources

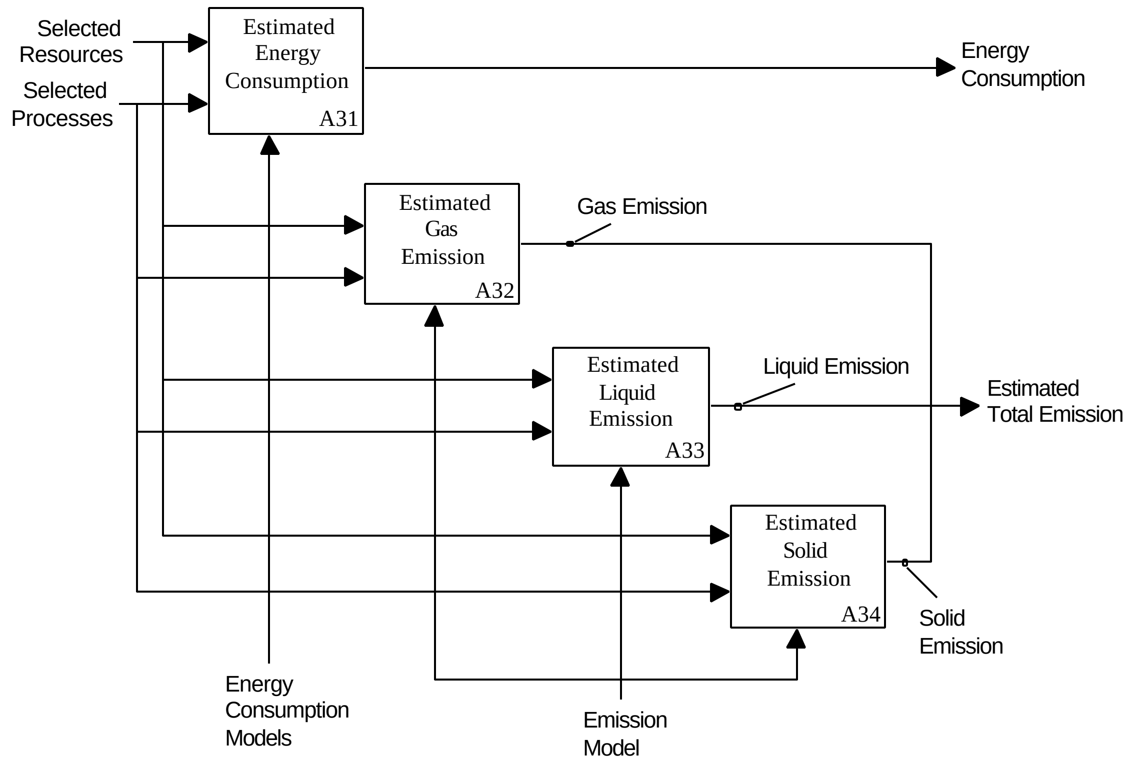

Figure 3 Environmental Impact Evaluation Activity

The object model is populated by a simple example of dry machining process of a test part. Classes and their attributes are populated. However, a more complicated dry machining case should be used to test the model as more research is conducted.

5 **Concluding Remarks and Future Directions**

Dry machining eliminates hazardous coolant from releasing to environment. It also reduces harmful substances that machining shop workers expose. Dry machining can be cost effective. Coolant usage costs about 48 billion Dollars a year in U.S., 1 billion German Marks in Germany, and 71 billion Japanese Yen in Japan a year. Dry machining is very likely to replace most wet machining processes in the near future.

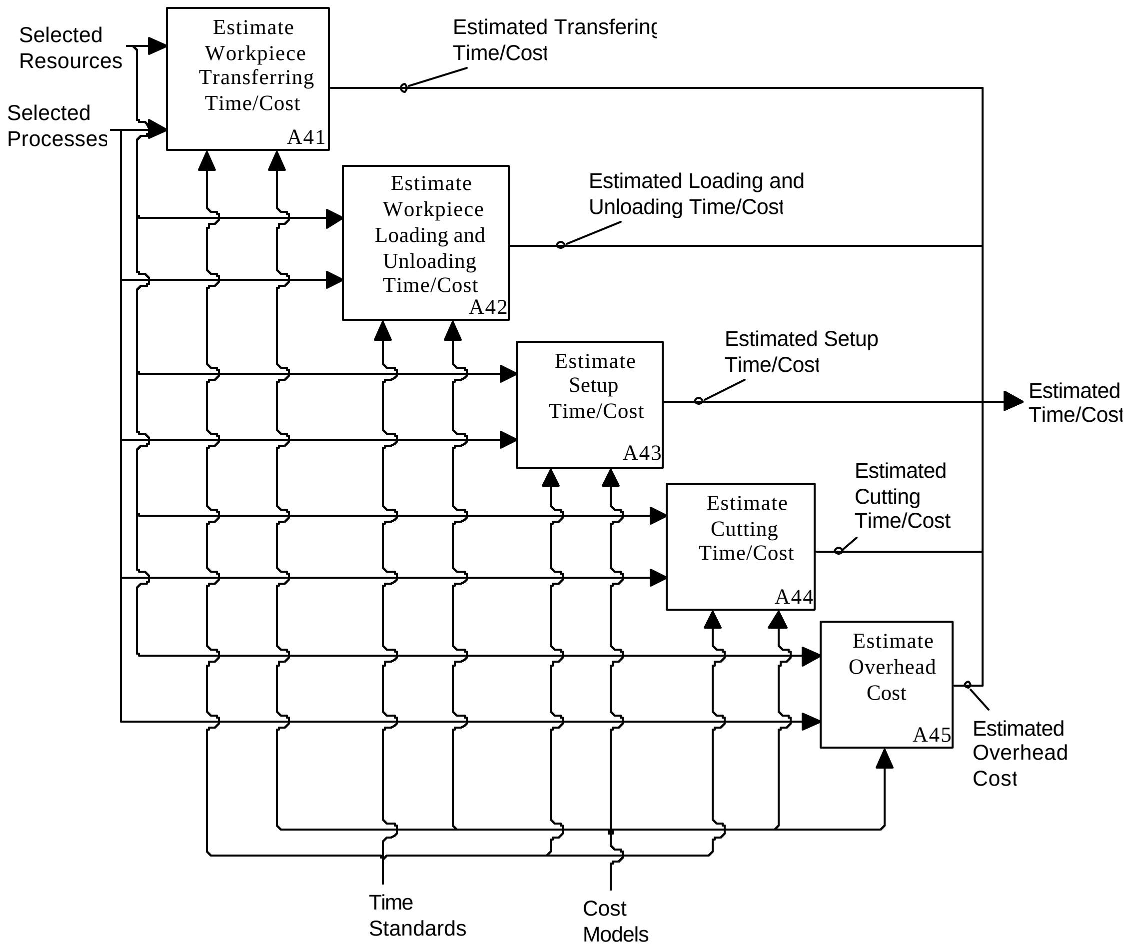

Figure 4 Machining Time/Cost Estimation Activity

Information models enable new software tool and databases development. New software tools help planning the dry machining process in saving planning time and enable the integration of dry machining processes with design.

Based on the cost and information models we have developed, future research directions should be in the following three directions: (1) to study the dry machining quality, especially the surface quality and dimensional accuracy, (2) to develop new methods on chip management to avoid machine jam, and (3) to populate the information model with more complicated process plans and update the model as necessary.

Acknowledgement

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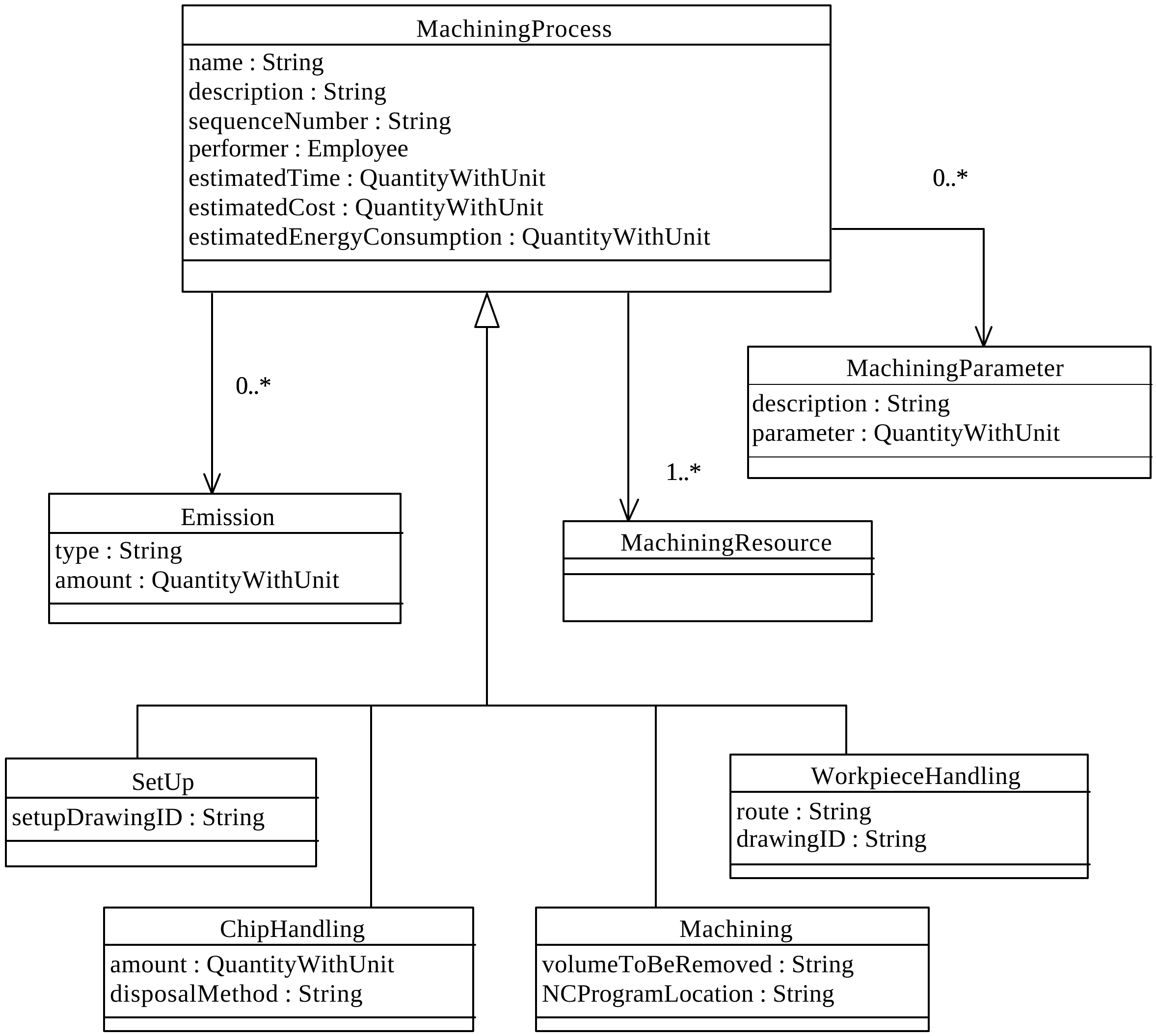

Figure 5 Machining Process Object Model

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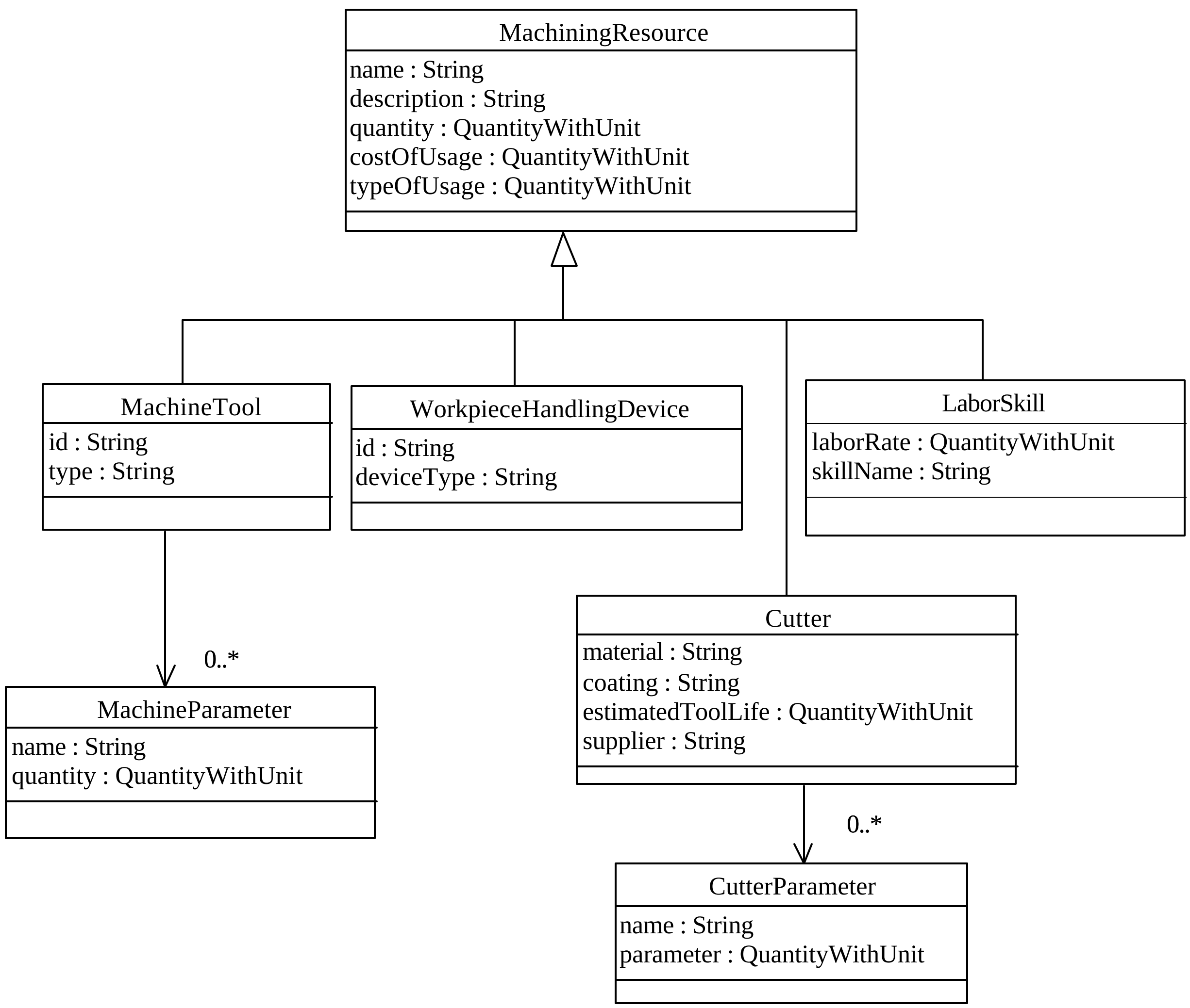

Figure 6 Resource Object model